IDENTIFICATION OF COLUMBIA BASIN SOCKEYE SALMON STOCKS USING SCALE PATTERN ANALYSES IN 1993

Technical Report 94-2

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May 31, 1994

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ABSTRACT

In 1993, the seventh year of the Columbia River Inter-Tribal Fish Commission's sockeye salmon stock identification research, a representative sample of the Columbia Basin sockeye salmon population was obtained at Bonneville Dam while an Okanogan known-stock sample was collected from Wells Dam (Columbia River km 829). A mixed Wenatchee-stock sample was collected at Tumwater Dam (Wenatchee River km 31) consisting of sockeye salmon of natural origin as well as unmarked fish from a hatchery/net-pen supplementation program. A small sample was also collected from the Methow River. The scales were examined to estimate the age of the fish and were also measured and used in stock identification experiments.

Age composition for all samples was estimated. Four-year-old fish were estimated to comprise 82% of the Bonneville Dam mixed-stock, 89% of the Okanogan known-stock, and 75% of the Wenatchee known-stock. Five-year-old fish were estimated to comprise 16% of the Bonneville Dam mixed-stock, 11% of the Okanogan stock, and 23% of the Wenatchee stock samples. For the first time, no fish sampled from any location were estimated to be three years old.

Using scale pattern analysis, 69% accuracy was achieved in classification of Age 1.2 fish of known origin. Fifty-nine percent of the Bonneville Dam mixed-stock Age 1.2 population was classified as Okanogan stock, 34% as Wenatchee stock, and 7% as Wenatchee hatchery/net-pen stock. Based on scale pattern analysis of the Age 1.2 samples, the small Methow sample appeared to be more similar to the Okanogan stock than the Wenatchee stock.

Fish from all sample sites were evaluated for physical injuries. At Bonneville Dam, 11% of the fish sampled were observed to be descaled, injured by marine mammals, or in some way cut or bruised. At Wells and Tumwater dams, 65 and 48% of fish sampled were similarly injured.

ACKNOWLEDGMENTS

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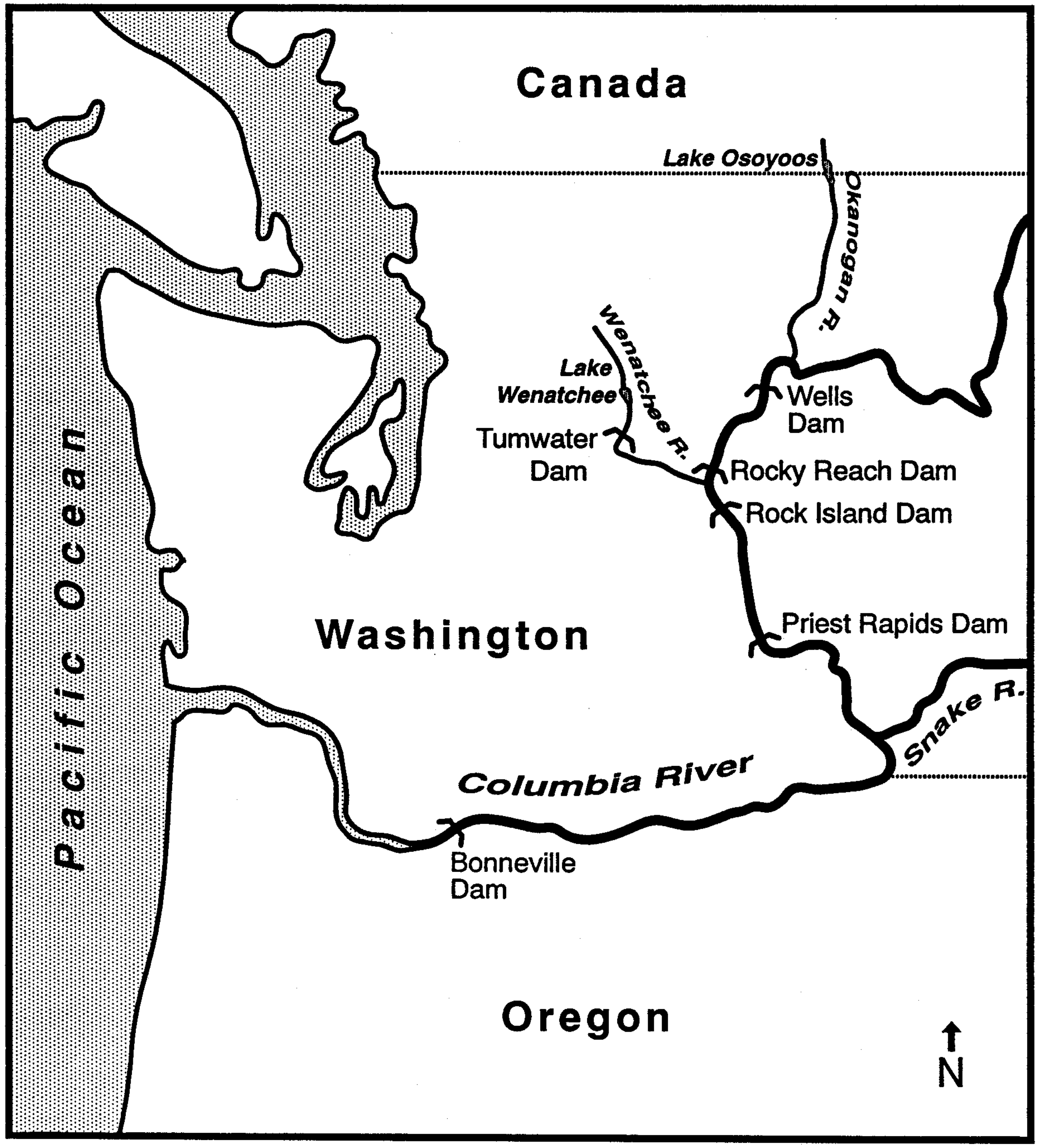
INTRODUCTION

Sockeye salmon *Oncorhynchus nerka* (Walbaum) is one of the five species of Pacific salmon native to the Columbia River Basin. Before white settlers developed the region, it is estimated the Columbia Basin supported an annual sockeye salmon run averaging over four million fish (Northwest Power Planning Council 1986). Since the mid-1800's, however, this sockeye salmon population has severely declined. The estimated number of sockeye salmon entering the Columbia River over the past four years (1990 through 1993) has averaged only 72,800 fish (CRITFC 1994).

The Columbia Basin sockeye salmon run was once composed of at least eight principal stocks (Fulton 1970). Today, only two major stocks remain (Figure 1). Historically, both stocks have been naturally produced, originating in the Wenatchee River-Lake Wenatchee System (Wenatchee stock) and in the Okanogan River-Osoyoos Lake System (Okanogan stock). In recent years, enhancement programs in both systems have been initiated that capture returning adults, spawn the adults in hatcheries, and raise the offspring in net pens located in the rearing lakes before release (Hays 1992, Wells Project Coordinating Committee 1992). Markedly different conditions exist in these remaining Columbia Basin sockeye salmon spawning and rearing areas (Allen and Meekin 1980, Mullan 1986). Lake Wenatchee is oligotrophic, with relatively deep, cold, and biologically unproductive waters. Conversely, Osoyoos Lake has the shallow, warm, and agriculturally enriched waters characteristic of eutrophic lake habitats.

Numerous potential uses exist for reliable estimates of the overall run composition of Columbia Basin sockeye salmon stocks and the biological and migratory characteristics of each stock. These include run-reconstruction studies to permit accurate population size forecasts, escapement monitoring, establishment of spawner-recruit relationships, and development of discrete stock approaches to Columbia River mainstem harvest management. The Pacific Salmon Treaty, ratified by the United States and Canada in 1985 (PST 1985), requires that certain Pacific salmon populations be monitored to determine the influence of Treaty-imposed ocean harvest regulations on *transboundary* stocks. Some Okanogan-stock sockeye salmon originating in Canadian waters but mi

Figure 1. Map of the Columbia Basin showing Bonneville, Priest Rapids, Rock Island, Rocky Reach, and Tumwater dams and the two principal sockeye salmon production areas.



grating through, and harvested in, the United States portion of the Columbia River might constitute such a stock. Stock identification research would aid in estimation of the proportion and abundance of Canadian-origin sockeye salmon caught within the United States. This study, begun in 1987, was initiated to provide such information (Schwartzberg and Fryer 1988).

Scale pattern analysis (SPA) was the method of study used for our stock identification research. SPA is a well-established stock identification and classification technique (Clutter and Whitesel 1956, Henry 1961, Mosher 1963, Anas and Murai 1969). In many species of fish, including Pacific salmon, the use of SPA as a tool for stock identification depends on a high correlation between individual fish growth and scale growth (Koo 1955, Clutter and Whitesel 1956). Fish growth and scale growth are influenced by genetic factors and by such environmental conditions as water temperature, length of growing season, and food availability. Stock identification based on SPA assumes that genetically or environmentally influenced growth patterns will differ throughout a species' range and that these differences will be exhibited in the scales of entire groups or stocks of fish. Scale samples from the Wenatchee and Okanogan sockeye salmon stocks in past years have differed (Schwartzberg and Fryer 1988, 1989, 1990; Fryer and Schwartzberg 1991, 1993; Fryer et al. 1992), presumably reflecting differences in freshwater spawning and rearing conditions.

This report presents estimates of the age, length-at-age, and stock composition of adult Columbia Basin sockeye salmon in 1993. The stocks examined included fish from Wenatchee and Okanogan naturally spawning stocks as well as fish from the Wenatchee hatchery/net-pen supplementation program (Hays 1992). Weekly and composite age and stock composition estimates for fish sampled at Bonneville Dam (mixed stocks of unknown origin) are presented. The relationship between migratory timing and age or stock composition was examined. If such a relationship exists, future mainstem sockeye salmon fisheries may be managed to target a specific stock or age class in the mixed-stock population. The relationship between migratory timing and age composition is also examined for each known stock. The size and stock selectivity of the Priest Rapids Dam Reservoir fishery is examined. A system for evaluating the physical condition of the sampled fish, based on visual assessment criteria developed in 1992, was used and the resulting data presented.

METHODS

Sampling

Sampling Methods

Scales from mixed sockeye salmon stocks (called *unknowns* or *unknown stocks*) were obtained from fish sampled at the Bonneville Dam Fisheries Engineering and Research Laboratory, located at river km 225 on the mainstem Columbia River. Each stock was also sampled in terminal areas to obtain representative scale samples for each of the two Columbia Basin sockeye salmon groups (*knowns* or *known stocks*). Wenatchee stock scales were collected at Tumwater Dam on the Wenatchee River (river km 31), while Okanogan stock scales were obtained at Wells Dam on the mainstem Columbia River (river km 829).

Fish were trapped, anesthetized, sampled for scales and length measurements, allowed to recover, and released (Schwartzberg 1987). Scales were collected and mounted according to methods described in Clutter and Whitesel (1956) and the International North Pacific Fisheries Commission (1963). Four scales per fish were collected to minimize the sample rejection rate. Observed mark and/or tag information was also recorded. The gender of specimens collected at Bonneville Dam could not be determined because all were in the earliest stages of sexual maturation. The gender of many specimens collected at Tumwater and Wells dams could be determined, and was recorded.

A large percentage of fish in our Okanogan-stock samples have, in recent years, been observed descaled or otherwise injured (Fryer and Schwartzberg 1991, Fryer et al. 1992). Causes for this are unknown and, in order to further study this phenomenon, in 1992 we developed criteria to quantify the external physical condition and appearance of adult salmon at Columbia Basin sampling locations (Fryer and Schwartzberg 1993). These criteria were modified and again applied in 1993 (Appendix A).

Scales were also obtained from eleven sockeye salmon carcasses sampled from the Methow River. Since there is no rearing lake on the Methow River, it is uncertain whether these fish are a separate stock that spawns in the Methow River and rears somewhere downstream (or upstream) of their point of emergence, or whether they are strays from the Wenatchee and/or Okanogan rivers.

Scales were also obtained from 152 sockeye salmon sampled from a tribal fishery conducted in the reservoir upstream of Priest Rapids Dam. This provided an additional mixed-stock sockeye salmon population sample. We used this additional sample to estimate the size and stock selectivity of this fishery.

Sample Design

Sockeye salmon were sampled at Bonneville Dam two days per week in conjunction with a summer chinook sampling program (Fryer and Schwartzberg 1994). Sampling at Tumwater and Wells dams was conducted one to two days per week during the period in which significant numbers of sockeye salmon were migrating past those sites. The desired total sample size for age composition estimates at each site was a minimum of 500 fish which, in previous study years, has resulted in acceptable levels of precision and accuracy ($d=0.05$, $\alpha=0.10$).

For SPA studies, the desired sample size was approximately 200 from each known-stock group (Conrad 1985). The Wenatchee stock subsample consisted of 216 systematically selected (subsampled) Age 1.2 specimens collected (see the following section entitled 'Age Determination and Scale Measurements' for a description of the age notation used herein). The Okanogan stock subsample consisted of 231 systematically selected (subsampled) Age 1.2 specimens. An additional 38 specimens (collected at Tumwater Dam) were judged, by comparing scale patterns with those of juveniles, to have originated from the Wenatchee hatchery/net-pen supplementation program. Although a minimum desired sample size of 100 is recommended for classification of unknown groups in SPA studies (Conrad 1985) such as the Bonneville Dam mixed-stock sample, 399 systematically selected (subsampled) Age 1.2 specimens from the mixed-stock sample were used in the analysis to permit more precise weekly stock

composition estimates. An additional 73 Age 1.2 mixed-stock group samples from the Priest Rapids Dam reservoir fishery were used in the analysis.

Minimum desired sample sizes were not obtained for any age class other than Age 1.2. Nevertheless, stock identification analyses were also performed on Age 1.3 and 2.2 specimens, even though sample sizes were small, and included 28 Okanogan known-stock, 41 Wenatchee known-stock, and 49 Bonneville Dam mixed-stock Age 2.2 samples, and 23 Okanogan known-stock, 54 Wenatchee known-stock, and 66 Bonneville mixed-stock Age 1.3 samples. Since the first fish released from the Wenatchee net-pen program were from the 1989 brood year, no Age 1.3 or 2.2 net-pen fish returned in 1993. The use of sub-minimal sample sizes for both Age 1.3 and 2.2 fish would be expected to reduce precision in sample classification for this age group.

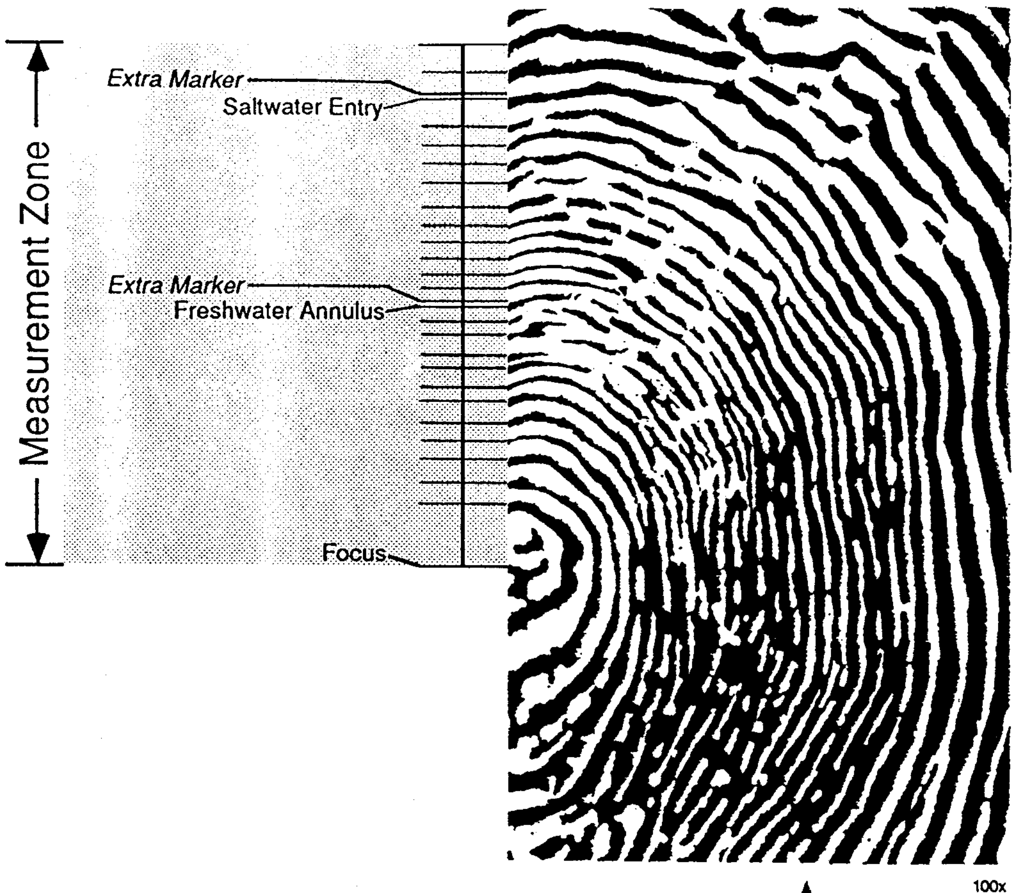
A stratified sampling method that weighted weekly age and length-at-age estimates by actual migratory timing was used to obtain composite estimates for the Okanogan known-stock and Bonneville mixed-stock (Cochran 1977). This method was not used for 1993 Wenatchee-stock estimates since no migratory timing data was available for the sample obtained at Tumwater Dam. Instead, the Wenatchee sample was treated as a simple random sample in the calculation of composite age and length-at-age estimates.

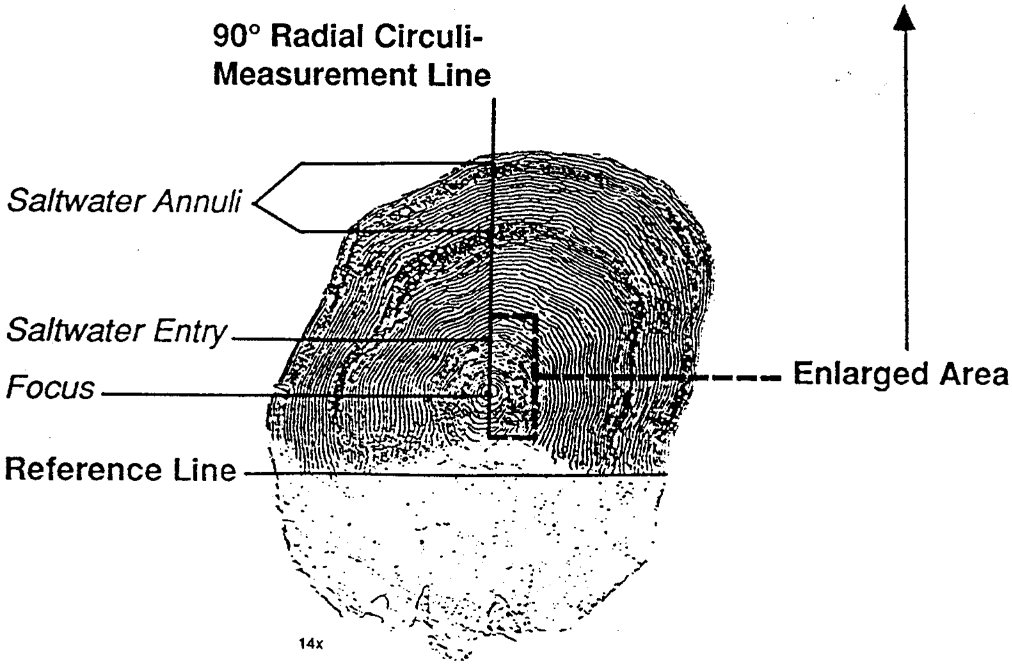
Age Determination and Scale Measurement

Under magnification, salmon scales display numerous concentric rings (*circuli*) radiating outward from a central focal area. A freshwater-growth zone of narrowly spaced circuli (Figure 2) is clearly distinguishable from a zone of more widely spaced saltwater-growth circuli in scales of Columbia Basin sockeye salmon. These fish typically spend one or two complete years in freshwater before migrating to the ocean. Fish age can be determined by counting *annuli*, the zones of closely spaced circuli formed yearly during winter and early spring periods of slow growth.

Using previously described techniques (Gilbert 1913, Borodin 1924, Van Oosten 1929), acetate scale impressions were magnified (56x) and examined

Figure 2. Age 1.2 Okanogan stock sockeye salmon scale showing growth and measurement zones.





visually. The method used for fish age notation is that recommended by Koo (1955), which is sometimes referred to as the *European* method. The number of winters a fish spent in freshwater (not including the winter of egg incubation) is described by an Arabic numeral followed by a period. The numeral following the period indicates the number of winters a fish spent in the ocean. Total age, therefore, is equal to one plus the sum of both numerals.

Scales were used to estimate the age composition of Bonneville Dam mixed-stock as well as the Okanogan and Wenatchee known-stock samples. Length-at-age relationships were also established for each stock. Scale ages were corroborated by Washington Department of Fisheries personnel. Validation of ages (Beamish and McFarlane 1983) was not possible because there were no specimens of verifiable known age in any of the samples.

SPA of circuli in freshwater- and early saltwater-growth zones was used to identify each known-stock sample and to also classify mixed stock samples. The methodology was applied to Age 1.2, 2.2, and 1.3 samples from all stocks. Scale features were first measured using a computer and video camera based system that included a microscope (2x, 4x, 6.3x, and 10x objectives; a 1.0x, 1.25x, and 1.5x magnification changer; and a 2.5x photocompensation adapter), a secondary monitor (33 cm), and a digitizing tablet connected to a 286 personal computer with a video frame-grabber board (BioSonics 1987). Acetate impressions of scales were placed in the microscope and projected onto the monitor using a 2.0x objective, 1.0x magnification changer, and 2.5x photo-compensation adapter. This lens configuration created a scale image viewed at 65x actual size.

One scale impression from each fish was selected and the projected image was oriented diagonally with the clear (posterior) part of the scale in the lower left corner of the screen. A reference line was drawn along the base of the scale image. The reference line was placed in the posterior field of the scale image so that the line bridged the end points of circuli in the first saltwater annulus (Figure 2). The objective was changed to 10x, resulting in a viewed scale image 325x actual size, and a radial line was then drawn perpendicular to the reference line. Circuli positions were measured at their points of intersection with the radial line. All measurements were made to the marginal (outermost) edges of cir-

culi. The zone measured included the entire freshwater zone and part of the early saltwater growth zone.

Additional circuli markers were placed to permit measurement of other key scale-features, specifically, freshwater annulus and saltwater-entry point. These features were respectively indicated by two sets of closely spaced circuli markers. The 'extra markers' were placed immediately after and adjacent to the original circuli position markers and were interpreted and removed by data analysis programs used in subsequent procedures (Appendix B). The freshwater annulus-position marker was placed beside the last circulus in the freshwater annulus and the saltwater-entry marker was placed immediately after the first circulus in the ocean zone.

Statistical Analyses

A linear discriminant analysis technique developed by Fisher (1936) was used to differentiate stocks and classify unknown mixed stock samples. Linear discriminant analysis permits the simultaneous use of many variables to form classification functions that typify and identify groups. This methodology has proven useful for determining the origins of individual fish stocks from mixed stock samples (Bethe and Krasnowski 1977, Bethe et al. 1980, Major et al. 1978).

Variables, composed of selected scale-measurements within the area from scale focus to Circulus 21, were tested to find those that most effectively characterized differences in growth between the two stocks. As in studies of previous years, distances between four adjacent circuli (or triplets), were the primary variable tested (Davis 1987). Other variables briefly tested included distances between adjacent circuli (singlets), three adjacent circuli (doublets), and five adjacent circuli (quadruplets). Distance measurements and number of circuli from scale focus to saltwater-entry and from scale focus to freshwater annulus margin (anterior) were also among the variables tested.

Accuracy of the discriminant analyses was determined by classifying the pooled known-stock samples from a particular analysis and then comparing re-

sults to actual (verifiable) known-stock identities. A jackknife procedure (Lachenbruch 1975, Dixon et al. 1983) was employed to correct for systematically biased results that are created in known-stock classification when the same samples are used for both calculating the discriminant function and estimating its accuracy. To correct for misclassification of unknown mixed stock samples, we used a method described by Cook and Lord (1978). To correct for unrealistic values, estimates of stock composition were constrained to the range of 0% to 100% using the method described by Cook (1983). Variances on mixed-stock classification estimates were also computed (Pella and Robertson 1979).

Length Measurements

Fork lengths were measured to the nearest 0.5 cm with the exception of specimens in the Priest Rapids Reservoir sample, which were measured to the nearest 0.1 cm. Mean lengths and measurements of variability were calculated for each age class. The mean lengths of sockeye salmon sampled at Bonneville Dam in this study were compared with mean lengths of samples from the Priest Rapids Reservoir using a two-sample test. Differences in the distribution of lengths of sockeye salmon between the two studies were tested using a Kolmogorov-Smirnov test (Hays 1988).

Visual Assessment of Physical Condition of Specimens

The physical condition of the sampled fish was evaluated, based on visual assessment criteria developed in 1992 (Appendix A).

Classification of Unknown Mixed-Stock Samples

Mixed-stock Age 1.2, 1.3, and 2.2 samples were classified using linear discriminant analysis techniques. Age 2.3 fish, typically present in the Wenatchee stock, but not in the Okanogan stock over the past six years of study, were all classified as Wenatchee stock.

Relationship of Migratory Timing to Stock and Age Composition

Tests were conducted to examine the relationship between migratory timing and stock and age composition in the mixed-stock sample. This relationship was tested by regressing mean weekly stock and age composition estimates against the statistical week[1] weighted by the inverse of the variance for each estimate (Neter et al. 1985).

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1. Statistical weeks are sequentially numbered calendar-year weeks. Excepting the first and last week of most years, weeks are seven days long, beginning on Sunday and ending on Saturday. In 1993 for example, Statistical Week 24 began on June 6 and ended on June 12.

RESULTS

Sample Sizes

Final sample sizes used for age and length-at-age composition estimates were 714 Bonneville mixed-stock, 150 Priest Rapids Dam Reservoir mixed-stock, 521 Wenatchee known-stock, 523 Okanogan known-stock, and 9 Methow stock. Of the original 733 sockeye salmon sampled at Bonneville Dam, 2% of the total sample was rejected and not classified by age because of unreadable scales. For the same reason, 1% of the 527 Wenatchee known-stock sockeye salmon sampled at Tumwater Dam, and 4% of the 546 Okanogan known-stock sockeye salmon sampled at Wells Dam were rejected.

Age Composition

The predominant age class for known and unknown stocks was Age 1.2. This age class was estimated to represent 89% of the Okanogan known-stock, 82% of the Bonneville mixed-stock, and 76% of the Wenatchee known-stock sample (Tables 1 and 2).

In the Methow River sample, 89% were estimated to be Age 1.2 and 11% were estimated to be Age 2.2.

In the Priest Rapids Reservoir fishery sample, 73% were estimated to be Age 1.2, 17% were estimated to be Age 1.3, 9% were estimated to be Age 2.2, and 1% were estimated to be Age 2.3.

Length Composition

Mean fork-lengths, calculated by age class, displayed little difference among fish collected at the three sampling locations (Figure 3). Length composition data for Methow River samples is not presented because of the small sam

Table 1. **Age composition estimates of Columbia Basin sockeye salmon at Bonneville Dam in 1993.**

Statistical Week	Sampling Dates	Sample Size	Brood Year and Age Class (%) 1990 1.1	1989 1.2	1989 2.1	1988 1.3	1988 2.2	1987 2.3
23-25	6/4,9,16,18	146	0	84	0	10	6	1
26	6/23,25	160	0	80	0	14	6	0
27	6/30,7/2	155	0	80	0	8	9	3
28	7/7,8	157	0	83	0	8	7	1
29	7/14,16	59	0	81	0	7	10	2
30	7/21,23	25	0	80	0	8	12	0
31-32	7/28,8/4	12	0	83	0	8	0	8
Population Estimate			0	81	0	10	7	1

Table 2. Age composition estimates of Wenatchee and Okanogan sockeye salmon stocks in 1993.

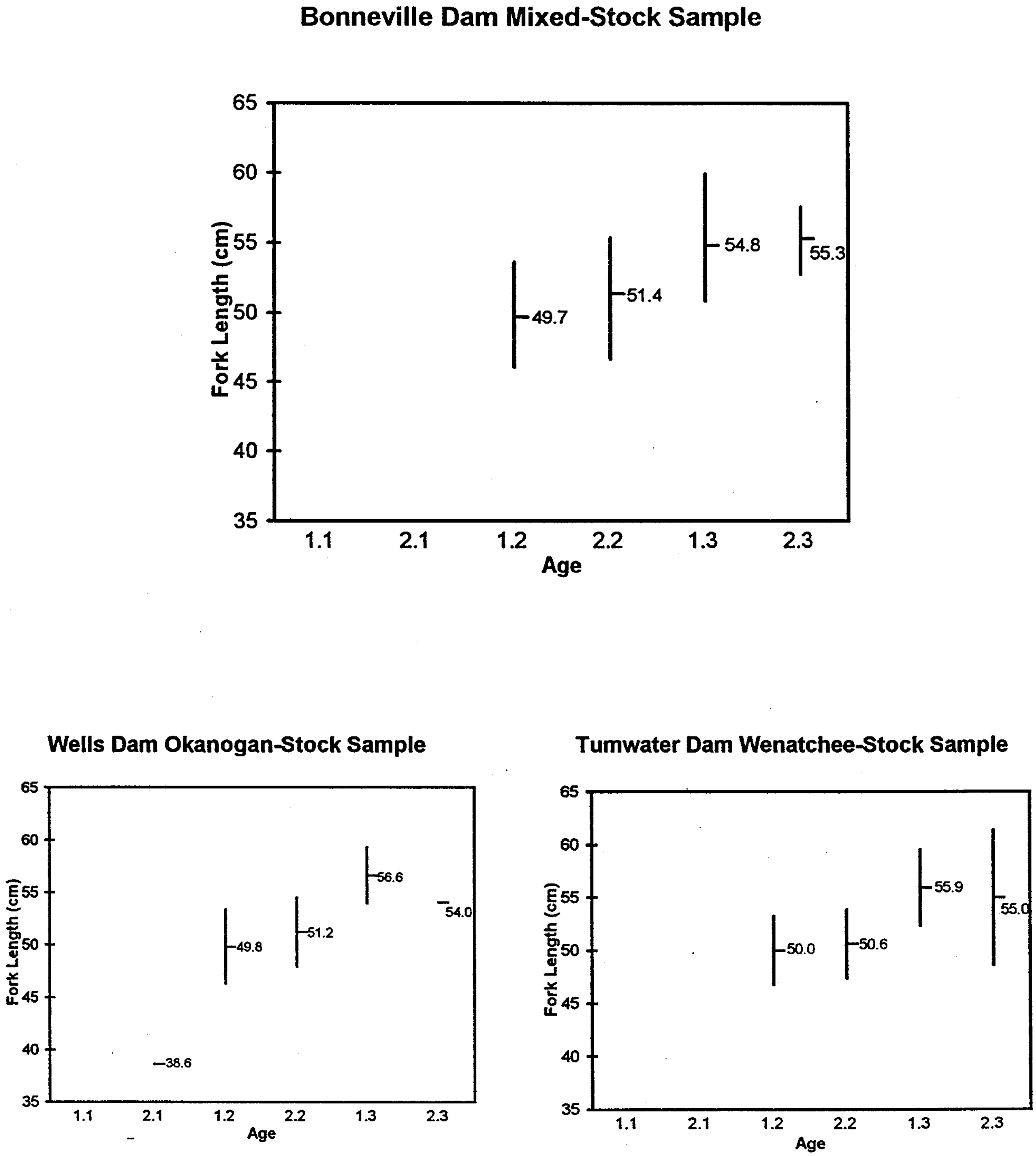
Wenatchee Stock Sampled at Tumwater Dam

Statistical Week	Sampling Dates	Sample Size	Brood Year and Age Class (%) 1990 1.1	1989 1.2	1989 2.1	1988 1.3	1988 2.2	1987 2.3
29	7/16	219	0	77	0	14	7	1
30	7/23	96	0	71	0	15	14	1
31	7/27	151	0	80	0	11	8	1
32	8/4	55	0	69	0	14	13	4
Population Estimate			**0**	**76**	**0**	**13**	**9**	**2**

Okanogan Stock Sampled at Wells Dam

Statistical Week	Sampling Dates	Sample Size	Brood Year and Age Class (%) 1990 1.1	1989 1.2	1989 2.1	1988 1.3	1988 2.2	1987 2.3
28	7/6	48	0	83	0	6	10	0
29	7/12	142	0	89	0	6	4	1
30	7/20	144	0	94	0	3	3	0
31	7/26	140	0	86	0	6	8	0
32	8/2	49	0	88	2	4	6	0
Population Estimate			**0**	**89**	**<1**	**5**	**6**	**<1**

Figure 3. **Length-at-age estimates (with 90% confidence intervals) for sockeye salmon stocks sampled at Bonneville, Tumwater, and Wells dams in 1993.**



ple size and inherent inaccuracies in measurements of specimens collected at spawning grounds.

The mean fork-length of sockeye salmon sampled in the Priest Rapids Reservoir fishery was 51.6 cm compared to 50.2 cm for the Bonneville Dam sample. This difference in mean fork lengths was significant ($p<0.001$) as was the difference in the length distribution in fish sampled at the two sites ($p<0.001$, Figure 4).

Visual Assessment of Physical Condition of Specimens

While only 11% of the specimens in the Bonneville mixed-stock sample exhibited some form of physical injury, 48% of the Wenatchee stock sample and 65% of the Okanogan stock sample exhibited such injuries (Table 3).

Classification of Known-Stock Samples

Among the variables tested, triplets resulted in among the highest classification accuracies and were used to provide consistency with results of previous years. As has been the case in previous years, those variables highly dependent on individual operator judgment were excluded to limit subjectivity. Therefore, although they were visually located and measured on each scale, variables directly related to freshwater annulus and saltwater entry positions were rejected from the final variable subset.

The classification of Age 1.2 fish was first treated as a two-stock problem, as in our previous studies when we compared Wenatchee natural-stock samples to Okanogan natural-stock samples. However, in 1993, because of the presence of an additional stock, the Wenatchee hatchery/net-pen stock, we needed to revise our experimental design. Therefore, we first compared all Okanogan stock samples to the pooled (two) stocks from the Wenatchee Basin, maintaining the two stock test design. After application of the jackknife procedure, 75% of the known-stock samples were accurately classified. However, 52% of the Wenatchee hatchery/net-pen specimens were classified as Okanogan stock.

Figure 4. **Cumulative length distribution of sockeye salmon sampled at Bonneville, Wells, and Tumwater dams and from the Priest Rapids Reservoir fishery in 1993.**

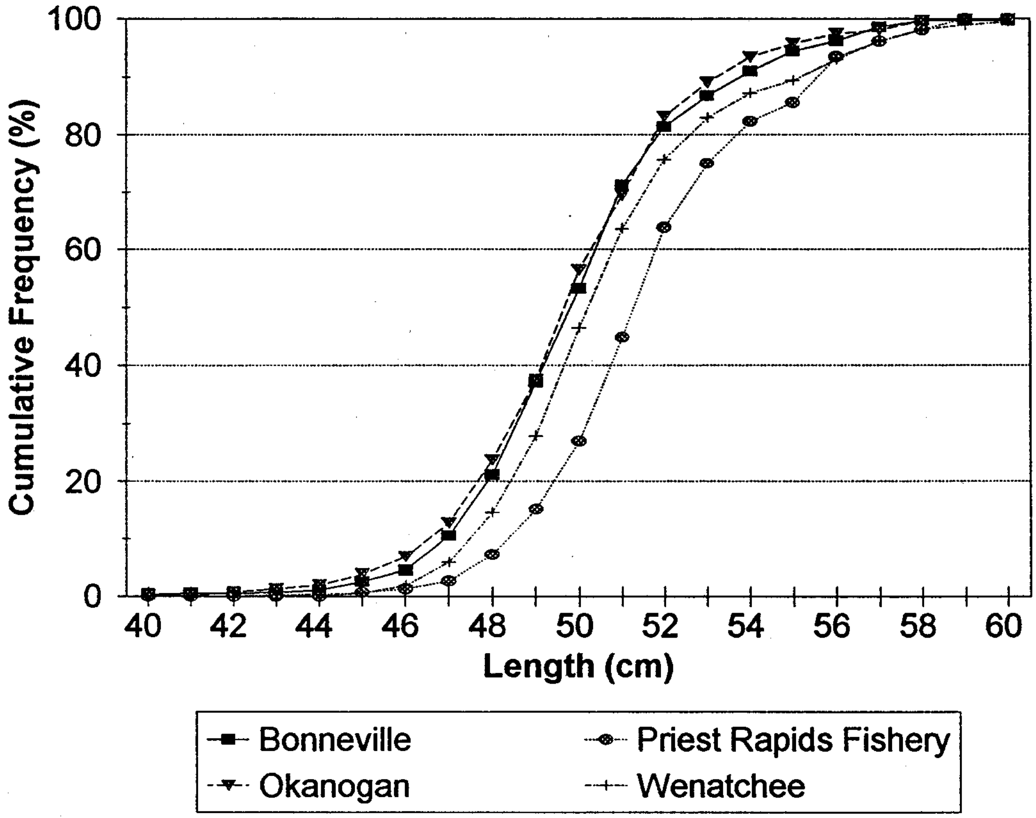


Table 3. **Estimated percentage of the Columbia Basin mixed- and known-stock sockeye salmon sample injured by marine mammals, gill nets, and other causes in 1993.**

Injury Category	Bonneville Stock	Okanogan Stock	Wenatchee Stock
Marine Mammal			
Bite	1	<1	<1
Claw Rake	4	2	1
Twin Arches	1	<1	<1
Total Marine Mammal[a]	6	3	2
Descaling			
5-20% Descaling			
Right Side	0	17	18
Left Side	<1	17	17
Either Side	<1	23	23
>20% Descaling			
Right Side	<1	5	2
Left Side	<1	3	3
Either Side	<1	6	5
General			
Bruise	1	10	4
Cut	<1	1	0
Eye Wound/Scar	<1	<1	0
Fin	<1	10	10
Fungus	1	1	0
Gash	<1	14	9
Gill Net Wounds/Scar	<1	6	4
Lamprey Wound/Scar	<1	<1	1
Nose	0	14	9
Parasite	0	0	0
Tail	2	10	7
Total General Injuries[a]	5	64	47
Total Injured[a]	11	65	48

a. Totals for these categories may not equal the sum of the subcategories due to either fish displaying more than one type of injury or injuries being noted but not accurately described.

Given the high rate of misclassification of this stock, a three-stock model was chosen for subsequent analyses that included Wenatchee natural, Wenatchee hatchery/net-pen, and Okanogan natural stocks.

The variables used by the stepwise procedure for the three-stock classification of Age 1.2 fish were the distances between the focus and third circuli, sixth and ninth circuli, ninth and twelfth circuli, twelfth and fifteenth circuli, and eighteenth and twenty-first circuli. After application of the jackknife procedure, 69% of the known-stock samples were accurately classified by this variable set (Table 4). Sixty-five of 216 Wenatchee, 67 of 231 Okanogan, and 13 of 38 Wenatchee hatchery/net-pen samples were misclassified.

The variables used by the stepwise procedure for the two-stock classification of Age 1.3 fish were the distances between the focus and third circuli and the ninth and twelfth circuli. After application of the jackknife procedure, 66% of the known-stock samples were accurately classified by this variable set (Table 4). Sixteen of 54 Wenatchee- and 9 of 23 Okanogan-stock samples were misclassified.

Classification of Unknown Mixed-stock Samples

After correcting for classification bias, 59% of the Age 1.2 sockeye salmon migrating past Bonneville Dam were estimated to be Okanogan stock (Table 5). An additional 34% of the Age 1.2 sockeye salmon population at Bonneville Dam was estimated to be Wenatchee natural stock while the remaining 7% was estimated to be Wenatchee hatchery/net-pen stock. Confidence intervals (90%) ranged from 51 to 67% for the Okanogan stock, from 26 to 42% for the Wenatchee natural-stock estimate, and from 0 to 14% for the Wenatchee hatchery/net-pen stock estimate.

Table 4. **Known-stock classification tests using linear discriminant analyses with Age 1.2 and 1.3 Columbia Basin sockeye salmon stocks sampled in 1993.**

Age 1.2 Samples

Stock	Percent Correct	Sample Classification *Wenatchee Natural*	*Wenatchee Hatchery*	*Okanogan Natural*
Wenatchee Natural	70	151	25	40
Wenatchee Hatchery	66	4	25	9
Okanogan	71	37	30	164
Composite Accuracy	69			

Age 1.3 Samples

Stock	Percent Correct	Sample Classification *Wenatchee Natural*	*Okanogan Natural*
Wenatchee Natural	70	38	16
Okanogan	61	9	14
Composite Accuracy	66		

Table 5. **Stock composition estimates of Columbia Basin sockeye salmon at Bonneville Dam in 1993.**

Classification of only Age 1.2 Sockeye Salmon[a]

Statistical Week	Sample Size	Sample Classification					
		Wenatchee Natural		*Wenatchee Hatchery*		*Okanogan Natural*	
		$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
23-25	78	28	10	5	9	67	12
26	82	45	10	2	8	53	11
27	79	38	10	15	9	48	11
28	79	27	10	5	9	68	12
29	48	18	12	11	12	71	14
30	21	0	17	0	11	100	19
31	12	0	24	0	6	100	25
Population Estimate		34	5	7	4	59	5

Classification of only Age 1.3 Sockeye Salmon[b]

Statistical Week	Sample Size	Sample Classification			
		Wenatchee Natural		*Okanogan Natural*	
		$\bar{x}$	s	$\bar{x}$	s
23-25	13	72	44	28	49
26	23	84	34	16	38
27	23	8	52	92	57
28-30	12	0	47	100	52
Population Estimate		37	34	63	36

a. Age 1.2 sockeye salmon composed 81% of the Bonneville Dam mixed-stock age composition estimate.

b. Age 1.3 sockeye salmon composed 10% of the Bonneville Dam mixed-stock age composition estimate

Table 5 (continued)

Classification of Sockeye Salmon of All Ages[c]

Statistical Week	Sample Size	Sample Classification: *Wenatchee Natural* $\bar{x}$	s	*Wenatchee Hatchery* $\bar{x}$	s	*Okanogan Natural* $\bar{x}$	s	*Unclassified* $\bar{x}$	s
23-25	146	32	11	4	8	59	12	6	2
26	160	48	11	2	7	45	12	6	2
27	155	34	10	12	8	46	12	9	2
28	157	24	10	4	8	64	12	7	2
29	59	16	12	9	11	64	14	10	4
30	25	0	16	0	10	88	20	12	7
31	12	8	24	0	6	91	27	0	0
Population Estimate		33	5	6	4	54	5	7	1

c. Combines the stock composition estimates from the preceding page. Samples of Age 2.3, composing 1% of the Bonneville Dam mixed-stock, were classified as Wenatchee stock (see text). Age 2.2 samples, composing 7% of the Bonneville Dam mixed-stock were not classified.

After correcting for classification bias, 64% of the Age 1.3 sockeye salmon migrating past Bonneville Dam were estimated to be Okanogan stock (Table 5). The remaining 36% of the Age 1.3 sockeye salmon population at Bonneville Dam was estimated to be Wenatchee natural stock. Confidence intervals (90%) ranged from 0 to 100% for the Okanogan stock and from 0 to 93% for the Wenatchee natural stock estimate.

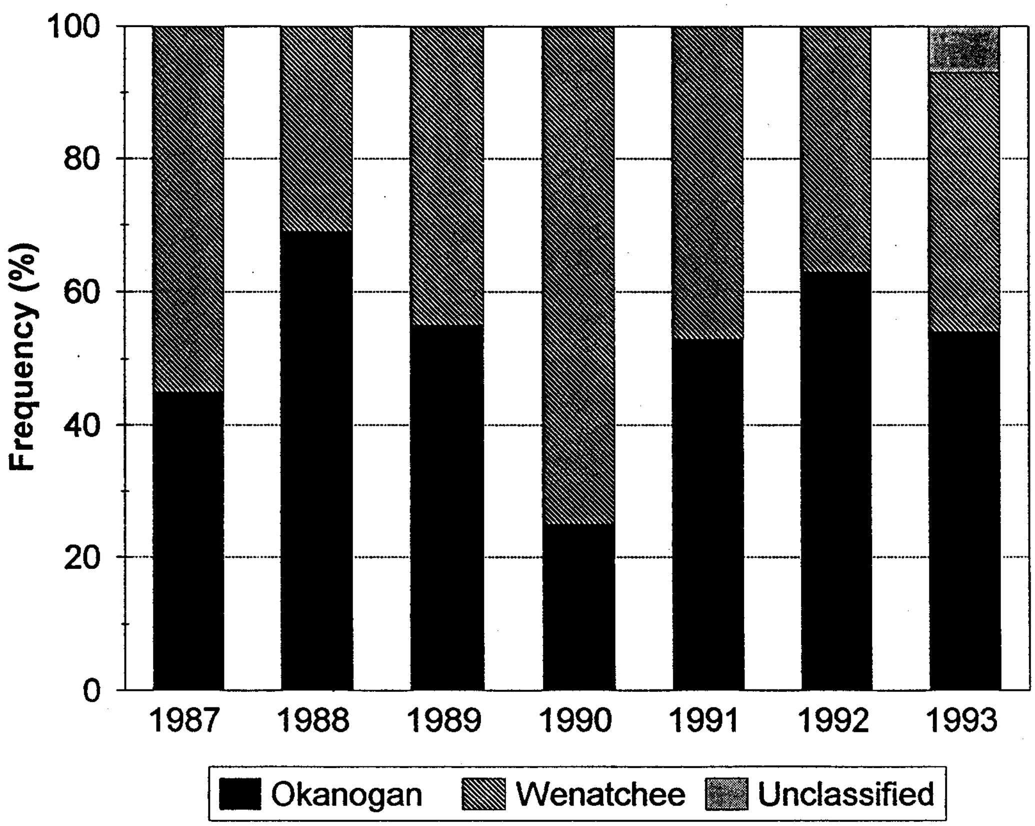
Scale patterns of both Age 2.2 Wenatchee and Okanogan fish were too similar to allow a classification function to be developed for SPA of mixed stock samples representing this age class. Therefore, these samples were not classified in the analysis and were reported as *unknown* in the results.

Combining the results of SPA classification of Age 1.2 and Age 1.3 sample of unknown stock origin (based on linear discriminant analyses), with the classification of Age 2.3 unknown samples (based on age alone); 54% of the Bonneville Dam mixed-stock sample was estimated to be Okanogan stock, 33% Wenatchee natural stock, and 6% Wenatchee hatchery/net-pen stock. The remaining 7% of the Bonneville Dam mixed-stock sample was classified as unknown (Table 5). Confidence intervals (90%) ranged from 48 to 62% for the Okanogan stock, from 25 to 41% for the Wenatchee natural stock, from 0 to 13% for the Wenatchee hatchery/net-pen stock, and from 5 to 9% for the unknown portion of the estimate. A comparison of this stock composition estimate with those made in previous years' studies is presented in Figure 5.

After correction for classification bias, and constraining values between 0 and 100%, all Age 1.2 Methow River sockeye salmon samples were classified as Okanogan stock (90% C.I. 55%, 100%). There were insufficient Methow River samples to use statistical techniques to consider the possibility that these fish might comprise a third stock.

After correcting for classification bias, and constraining values between 0 and 100%; 69% of the Priest Rapids Dam Reservoir Age 1.2 samples were estimated to be Wenatchee natural stock. The remaining 31% were classified as Okanogan stock. Confidence intervals ranged from 58 to 78% for the portion of the (Age 1.2) population estimated to be Wenatchee stock, 21 to 39% for the Okanogan stock, and 0 to 5% for the Wenatchee hatchery/net-pen stock.

Figure 5. **Stock composition estimates of Columbia Basin sockeye salmon stocks at Bonneville Dam from 1987 through 1993.**



Relationship of Migratory Timing to Stock Composition

Weekly unknown mixed-stock composition estimates (Table 5) show a significant relationship at $\alpha=0.10$ between migratory timing and the relative abundance of both Okanogan ($p=0.07$) and Wenatchee ($p=0.02$) natural stocks at Bonneville Dam. No significant relationship was observed between migratory timing and the relative abundance of Wenatchee hatchery/net-pen sockeye salmon ($p=0.36$). These tests indicate that, in 1993, the relative proportion of Okanogan-stock sockeye salmon increased as the mixed-stock migration progressed. Conversely, the relative proportion of Wenatchee-stock sockeye salmon decreased over the migratory period. Overall however, Okanogan-stock fish predominated throughout the migratory period.

Age composition analyses using a similar linear regression technique indicated that the relative abundance of Age 1.1, 1.3, and 2.2 sockeye salmon in the 1993 unknown mixed-stock sample (Tables 1 and 2) was not related to migratory timing at $\alpha=0.10$ for either mixed or known stocks ($p>0.15$ for all tests).

DISCUSSION

This paper reports results from the seventh year of a Columbia Basin sockeye salmon stock identification research project (Schwartzberg and Fryer 1988, 1989, 1990; Fryer and Schwartzberg 1991, 1993; Fryer et al. 1992). Throughout this study, Wenatchee- and Okanogan-stock sockeye salmon have been identified using a linear discriminant analysis procedure. Classification accuracies (using Age 1.2 scale samples) have ranged from 65% in 1990 to 91% in 1987. In 1993, we performed a three-stock analysis for the first time to account for the presence of a new Wenatchee hatchery/net-pen stock

In 1993, as in most previous years, Age 1.2 was the predominant estimated age class in both known stocks, as well as in the mixed stock. In previous study years Age 1.3 and 2.2 sockeye salmon were present in significant numbers only in the Wenatchee stock. In 1993, however, fish of these age classes were also observed in substantial numbers in the Okanogan stock. No fish of Age 1.1 or 2.1 were observed in the Okanogan stock in 1993, another marked difference from previous study years. This finding may have some value in future run-size prediction models. In Columbia Basin spring chinook salmon, the number of Age X.1 (or *one-ocean fish*) has been found to be an indicator of the number of Age X.2 (or *two-ocean fish*) returning in the following year (Fryer and Schwartzberg 1994). If this relationship holds for Okanogan-stock sockeye salmon, the low abundance of Age X.1 sockeye salmon in 1993 that we report herein predicts very poor 1994 adult returns for the typically predominant Age X.2 fish. We are presently conducting further research into similar run prediction techniques.

Our estimate of sockeye salmon stock composition at Bonneville Dam differed from that based on fish counts made at mid-Columbia River hydroelectric projects where adult migrating salmon are visually counted in fish ladders, predominately during daylight hours (Mullan 1986). Except for a remnant Snake River stock, all surviving Columbia Basin adult sockeye salmon stocks migrate past Rock Island Dam (river km 729). However, only Okanogan stock fish pass Rocky Reach Dam (river km 761) because the Wenatchee River enters the Columbia River at kilometer 753, located between Rock Island and

Rocky Reach dams, and because there is no reported sockeye salmon spawning habitat in the impounded inter-dam river area. Using a stock composition estimation technique based on these counts, the proportion of Wenatchee-stock fish is estimated by the difference between Rock Island and Rocky Reach dam sockeye salmon counts divided by the Rock Island Dam count. The proportion of Okanogan-stock fish is estimated by the Rocky Reach Dam count divided by Rock Island Dam count. Using this method, 57% (35,320) and 43% (26,629) of the 1993 sockeye salmon escapement estimate at Rock Island Dam was estimated as Okanogan and Wenatchee stock.

Our Columbia Basin sockeye salmon stock composition estimate based on scale pattern analysis estimated that 54% of the sockeye salmon at Bonneville Dam were Okanogan stock, 39% Wenatchee stock, and the remaining 7% unknown. If the unknown origin fish are allocated proportionally to the two stocks, our adjusted estimate is 58% Okanogan and 42% Wenatchee stock. These stock composition estimates are significantly different from those based on the visual count method (p=0.01 Okanogan, p=0.03 Wenatchee)[2]. A possible explanation for these differing estimates of stock composition is that the Wenatchee and Okanogan sockeye salmon stocks encountered different rates of mortality on the 1993 upstream migration. Another possible explanation is that our study collected a sample at Bonneville Dam which did not accurately represent the entire population. Finally, consideration should be given to the possibility that 1993 visual sockeye counts were inaccurate. This latter explanation is particularly likely given the unexplained variability of the visual counts of sockeye salmon reported at mainstem Columbia River dams in 1993 (CRITFC 1994). Since few sockeye salmon are observed spawning in the Columbia Basin or its tributaries downstream of Rock Island Dam, it would be expected that counts at dams between Bonneville and Rock Island should be similar or should decrease successively because of adult migrant mortality at dams (Northwest Power Planning Council 1986). However, 1993 counts reported did not follow this pattern and often increased as the geographic dis-

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2. In this analysis, visual counts were assumed to be accurate to within d=0.05, α=0.05 (G. Johnson, U.S. Army Corps of Engineers, Portland, personal communication).

tance upstream of Bonneville Dam increased[3]. Given this high variability, estimates of 1993 stock composition based on SPA presented in this study are probably more accurate than those based on dam counts.

In 1993, a significant linear relationship was found between the estimated stock composition and the migratory timing of the sockeye salmon at Bonneville Dam. The percentage of Wenatchee-stock fish decreased as the migration progressed, while the percentage of Okanogan-stock fish increased. A similar significant relationship was found in 1989, 1990, and 1992, but not in 1991. If a consistent and predictable relationship is found between stock composition and migratory timing, adjustment of potential future mainstem Columbia River sockeye salmon fisheries may be possible to manage the harvest of a greater proportion of a particular stock.

Fewer physical injuries were observed at all sample sites in fish sampled in 1993 compared with 1992 (Fryer and Schwartzberg 1993). The percentage of injured Okanogan stock fish decreased from 90 to 65%. The percentage of injured Wenatchee stock fish decreased from 81 to 48%, and the percentage of injured mixed-stock (Bonneville Dam) fish from 17 to 11%. Possible reasons for this decrease may include higher Columbia River flows and cooler water temperatures in 1993 compared to river conditions during the adult sockeye salmon migratory period in 1992.

Significant numbers of adult sockeye salmon originating in the Wenatchee hatchery/net-pen supplementation program (Hays 1992) were observed in our samples for the first time in 1993. Since none of the fish released from the 1989 brood year were tagged, scale pattern analysis was the only method to evaluate adult returns and the relative contribution of this program. We used the difference of Rock Island and Rocky Reach dam sockeye salmon counts as an estimate of total Wenatchee sockeye salmon abundance and a visual analysis of scale patterns to estimate the proportion of hatchery/net-pen origin fish. Combining data from these two methods, we estimate a total return

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3. Reported 1993 sockeye salmon visual counts at the six mainstem Columbia River dams downstream of Rock Island Dam were: Bonneville 80,182; The Dalles 62,252; John Day 61,220; McNary 66,484; Priest Rapids 82,966; and Rock Island 61,949 (CRITFC 1994).

of 1800 adult fish in 1993 from the hatchery/net-pen program (90% c.i.=0, 3600). Based on a release of about 260,400 presmolts in October 1990 (Lavoy 1993), the presmolt-to-adult survival (from release point to return at Tumwater Dam) was 0.7%.

Our SPA work, performed in this year's study, suggests that Methow River sockeye scale patterns are more similar to the Okanogan than the Wenatchee natural stock. This differs from our 1992 study results when both the age distribution and SPA of Methow River sockeye salmon samples suggested that these fish were more similar to the Wenatchee natural stock. The Methow River sample was too small in both 1992 and 1993 to use this stock as a known stock in our SPA model. It is hoped that a larger sample size can be obtained from Methow River spawning sockeye salmon in 1994 to further explore characterizing this population. Whether these fish comprise a separate stock or are stray fish from the Okanogan and/or Wenatchee stocks has long been questioned. Previous studies have considered the existence of a distinct Methow River stock based on releases of Winthrop Hatchery stock fish in the Methow River from 1942 through 1957 (Mullan 1986). An electronic counting weir on the Methow River counted 357 sockeye in 1965 and 1,013 sockeye in 1966 (Meekin 1967). In recent years, sockeye salmon have commonly been observed spawning between river km 57 and 64, just downstream of the town of Twisp and 43 sockeye salmon redds were observed in this area in 1993 (M. Miller, Don Chapman Consultants, Boise; personal communication). The lack of a natural rearing lake for juvenile Methow sockeye salmon has led other scientists to theorize that these fish are actually strays from elsewhere in the Columbia Basin (Pratt et al. 1991). They base their theory on the observation that it is rare to find sockeye stocks which rely on rivers or estuaries for juvenile rearing habitat (Burgner 1991). Columbia River mainstem reservoirs have relatively small volumes and high flushing rates and appear to offer potentially poor rearing habitat for Methow sockeye salmon juveniles (Mullan 1986).

Research on Columbia Basin sockeye salmon will continue in 1994 and we will continue to develop an age, length-at-age, and stock composition database for this population. Data obtained from this program may be useful to monitor the impact of future main-stem Columbia fisheries, supplementation

programs in the Wenatchee and Okanogan basins, as well as sockeye salmon stock recovery efforts in other Columbia River subbasins.

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APPENDIX A. Description of fish condition assessment notation.

Prior to 1992, sampling personnel in this study had the option of noting the condition of fish in the *comments* section of the sampling form used. This resulted in an assessment of fish condition which varied with sampling personnel, sampling site, and sampling date. In an effort to standardize this information and to allow meaningful comparisons of relative fish condition by date or site, new criteria and sample forms (Figure A1) were developed for the 1992 sampling season (Fryer and Schwartzberg 1993) and the following criteria for injury evaluation were used in 1993:

Injuries to be noted:

1. Gill Net
2. Descaling, left side; estimate actual percentage descaled
3. Descaling, right side; estimate actual percentage descaled
4. Marine mammal injuries as follows:
   - **C:** Claw Rake (2-3 or more parallel scratches on flanks of fish)
   - **G**: Twin Arches (2-3 or more curved scratches on flanks of fish)
   - **B**: Bite (Ragged wounds, often in caudal area)
5. General injuries as follows:
   - **E:** Eye
   - **N**: Nose
   - **H:** Fish Hook
   - **P**: Parasite
   - **L**: Lamprey, circular wound
   - **RP, LP, LV, RV, D, A, T** (Tail or Caudal Fin): Fin
   - **C:** Cut
   - **F:** Fungus
   - **B:** Bruise
   - **G:** Gash or lesion

For all injuries, a plus (+) indicates the injury is judged severe (extensive scarring or blood/flesh visible). A check (√) indicates that the injury is judged to have recently occurred (i.e. on the upstream migration).

Figure A1 Sampling form used in sockeye salmon sampling.

CRITFC STOCK IDENTIFICATION PROJECT SAMPLING FORM

LOCATION:________________ SPECIES:________________ PAGE:______OF______

DATE:________________ WEEK:________________ SAMPLERS:__________

Scale Card #	Position	Fork Length	Mid-Eye Length	Gender	Gill Net Damage	Descaling Left	Descaling Right	Marine Mammal	General Injures	Fin Clip	Comments	Scale Card #	Position	Fork Length	Mid-Eye Length	Gender	Gill Net Damage	Descaling Left	Descaling Right	Marine Mammal	General Injures	Fin Clip	Comments
	1												1										
	2												2										
	3												3										
	4												4										
	5												5										
	6												6										
	7												7										
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APPENDIX B. Data handling and manipulation for scale pattern analysis.

During the scale data acquisition process, information associated with each scale data record is stored along with actual scale measurements in four separate fields of the data record *header* (Optical Pattern Recognition System, OPRS; BioSonics Inc. 1985). The sample number, denoted by the appropriate scale card and the sample position number (separated by a period) is recorded in the *sample id* field. Thus, sample number 3 on card number 1 would be recorded as 1.03. The estimated age of the fish from which the scale sample was taken is recorded in the *specimen id* field while the length, sex (M, F, or U), and stock (if known) are recorded in the field labeled *other.* In addition to this user supplied information, the header includes system supplied data including a sequential record number, the microscope magnification conversion factor, a microscope lens calibration factor, a record validity indicator, the total number of circuli in the record, and the angle of the radial line used.

Once circuli measurements are made and a scale data record is saved to the computer's hard disk, scale measurement data cannot be further edited. The operator may, however, edit user supplied header information. The desired record can be located and displayed (by using the OPRS *EDT* page and the *display data* command). Each record is displayed and contains header information and distance measurements from the scale focus to each circulus measured in *sampling units* (Figure B1). Measurements in sampling units can range from 1 to 700 and must be multiplied by the microscope magnification conversion factor to determine metric distances from the scale focus to each marked circulus. Each circulus measurement is stored on a separate line.

To more effectively edit and prepare data for further statistical analysis, the *convert to ASCII* feature of the EDT page is used. This command creates an ASCII file that can be manipulated by a program we have written that detects the extra markers in each record (marking freshwater annulus margin (anterior) and saltwater entry point), converts scale data measurements to actual metric distances, and stores this information in a more compact format (Figure B2). Using still another program, the information necessary to perform statistical analyses is extracted from this file and transferred to statistical software.

Figure B1. **A sample OPRS data record for a single sockeye salmon scale freshwater-growth-zone measurement.**

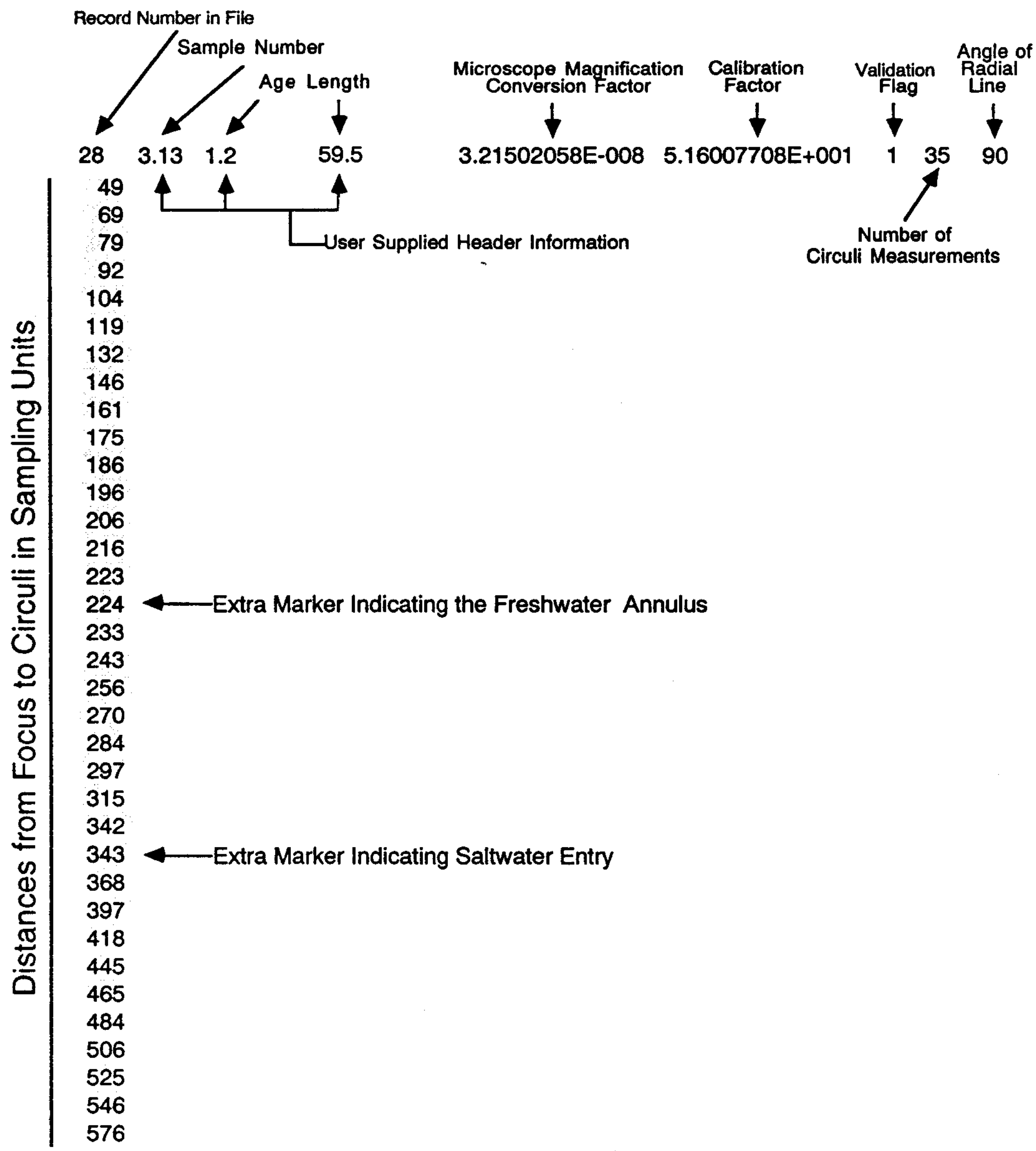

Figure B2. **A sample compact-format data record for a single sockeye salmon scale freshwater-growth-zone measurement.**

Sample Number — Sample Age — Sample Length (cm) — Number of Circuli — Distances from Focus to Circuli in Micrometers

3.13	1.2	47.5	33	*1.57536*	*2.21836*	*2.53987*	*2.95782*
2.95782							
3.34362	*3.82587*	*4.24383*	*4.69393*	*5.17618*	*5.62629*	*5.97994*	*6.30144*
6.62294	*6.94444*	*7.16950*	*7.49100*	*7.81250*	*8.23045*	*8.68056*	*9.13066*
9.54861	*10.12731*	*10.99537*	*11.83128*	*12.76363*	*13.43879*	*14.30684*	*14.94985*
15.56070	*16.26800*	*17.55401*	*18.51852*	15	23		

Number of Circuli from Focus to Freshwater Annulus (15)

Number of Circuli from Focus to end of Freshwater Growth Zone (23)